Quantum mechanical 'Backward in Time'? Comments, Answers, and the Causal Indistinguishability Condition

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Abstract

We discuss a number of comments on quant-ph/9801061, and propose to introduce the concept of 'Causal Indistinguishability'. The incompatibility between Quantum Mechanics and Nonlocal Causality appears to be unavoidable: upholding of Quantum Mechanics by experiment would mean to live with influences backward in time, just as we are now living with such faster than light.

Keywords: superposition principle, causal indistinguishability, backward in time, relativistic nonlocal causality, multisimultaneity.
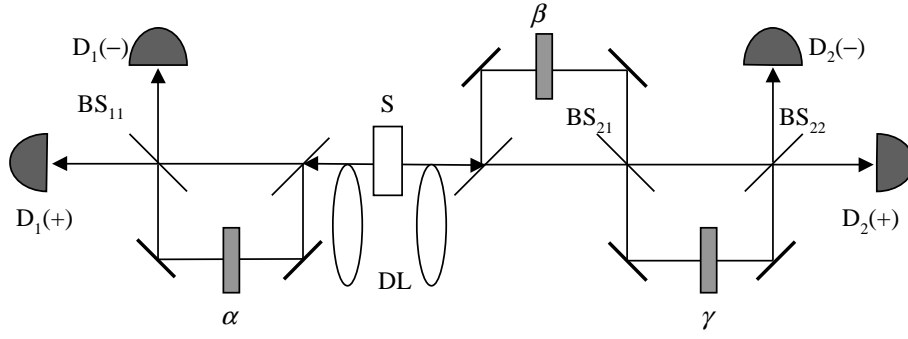
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Figure 1: Impact series experiment with photon pairs. See text for detailed description.

1 Introduction

In two recent papers [1, 2] impact series experiments using the setup represented in Fig. 1 have been proposed, and argued the quantum mechanical superposition principle to imply influences acting backward in time, and therefore to be at odds with the causality principle, and, in particular, with the multisimultaneous causal view. For the sake of convenience we present once again in section 2 the quantum mechanical view. In section 3 we discuss the main comments received to date, most of them as private communications and at the occasion of seminar presentations. This discussion brings forward the concept of *causal indistinguishability*, which is used in section 4 to improve the multisimultaneous causal description [3, 4, 5, 6]. A possible real experiment is discussed in section 5, and in section 6 it is concluded that the conflict between Quantum Mechanics and Causality cannot be escaped.

2 The quantum mechanical view

Consider again the setup sketched in Fig.1. Photon 1 enters the left hand side interferometer and impacts on beam-splitter BS_{11} before being detected in either $D_1(+)$ or $D_1(-)$, while photon 2 enters the 2-interferometer series on the right hand side impacting successively on BS_{21} and BS_{22} before being detected in either $D_2(+)$ or $D_2(-)$. Each interferometer consists in a long arm of length L, and a short one of length l. We assume the path difference $L - l$ set to a value which largely exceeds the coherence length of the photon pair light, but which is still smaller than the coherence length of the pump laser light. For a pair of photons, eight possible path pairs lead to detection. We label them as follows: (l, ll); (L, ll); (l, Ll) and so on; where, e.g., (l, Ll) indicates the path pair in which photon 1 has taken the short arm, and photon 2 has taken first the long arm, then the short one. By means of delay lines DL different time orderings in the laboratory frame can be arranged.

We distribute the ensemble of all possible paths in the four following subensembles:

2

$$
\begin{array}{lcl}
(l, LL) & : & 2L - l \\
(L, LL), \ (l, Ll), \ (l, lL) & : & L \\
(l, ll), \ (L, Ll), \ (L, lL) & : & l \\
(L, ll) & : & 2l - L
\end{array}
\tag{1}
$$

where the right-hand side of the table indicates the path difference between the single paths of each photon characterizing each subensemble of path pairs.

By means of delay lines DL different time orderings can be arranged. We are mainly interested in the following two:

1. *Time ordering 1:* The impact on BS_{22} and detection at $\mathrm{D}_2(\omega)$, lie time-like separated before the impact on BS_{11}.

2. *Time ordering 2:* The impact on BS_{11} and detection at $\mathrm{D}_1(\sigma)$, lie time-like separated before the impact on BS_{21}.

According to the conventional quantum mechanical definition of indistinguishability the three paths belonging to subensemble L have to be considered indistinguishable, and the same holds for the three paths belonging to subensemble l. Moreover ordinary QM assumes indistinguishability to be a sufficient condition for observing quantum interferences and entanglement. Therefore the superposition principle states for any possible time ordering:

$$
P_{\sigma\omega}^{QM}(L) = |A_{\sigma\omega}(L, LL) + A_{\sigma\omega}(l, Ll) + A_{\sigma\omega}(l, lL)|^2
\tag{2}
$$

where $P_{\sigma\omega}^{QM}(L)$ $(\sigma, \omega \in \{+, -\})$ denotes the joint probability of getting the outcome specified in the subscript for a path of subensemble L, and $A_{\sigma\omega}(path)$ the corresponding probability amplitudes for the path specified in the parenthesis.

Substituting the amplitudes given in (27), (28) and (29) of the Appendix into Eq. (2) yields the following values for the conventional joint probabilities:

$$
\begin{aligned}
P_{++}^{QM}(L) &= \frac{1}{12}\Big[3 - 2\cos(\alpha + \beta) - 2\cos(\alpha + \gamma) + 2\cos(\gamma - \beta)\Big] \\
P_{+-}^{QM}(L) &= \frac{1}{12}\Big[3 - 2\cos(\alpha + \beta) + 2\cos(\alpha + \gamma) - 2\cos(\gamma - \beta)\Big] \\
P_{-+}^{QM}(L) &= \frac{1}{12}\Big[3 + 2\cos(\alpha + \beta) + 2\cos(\alpha + \gamma) + 2\cos(\gamma - \beta)\Big] \\
P_{--}^{QM}(L) &= \frac{1}{12}\Big[3 + 2\cos(\alpha + \beta) - 2\cos(\alpha + \gamma) - 2\cos(\gamma - \beta)\Big]
\end{aligned}
\tag{3}
$$

From (3) one is led to the following correlation coefficient:

$$
E^{QM} = \sum_{\sigma,\omega}(-\sigma\omega)P_{\sigma\omega}^{QM}(L) = \frac{2}{3}\cos(\alpha + \gamma),
\tag{4}
$$

We are also interested in the single probabilities at each side of the setup, i.e., the probability of getting a count in detector $D_2(\sigma)$ independently of where photon 1 is detected, which we denote $P_{\pm\sigma}^{QM}(L)$, and the probability of getting a count in detector $D_1(\sigma)$ independently of where photon 2 is detected, which we denote $P_{\sigma\pm}^{QM}(L)$.

The single probabilities are related to the conventional joint ones as follows:

$$P_{\pm\omega}^{QM}(L) \equiv P_{+\omega}^{QM}(L) + P_{-\omega}^{QM}(L), \tag{5}$$

and

$$P_{\sigma\pm}^{QM}(L) \equiv P_{\sigma+}^{QM}(L) + P_{\sigma-}^{QM}(L). \tag{6}$$

Eq. (3) leads to the corresponding single probabilities for the detections at side 2 (right-hand side) of the setup:

$$P_{\pm+}^{QM}(L) = \frac{1}{2} + \frac{1}{3}\cos(\beta - \gamma)$$
$$P_{\pm-}^{QM}(L) = \frac{1}{2} - \frac{1}{3}\cos(\beta - \gamma), \tag{7}$$

and at side 1 (left-hand side) of the setup:

$$P_{+\pm}^{QM}(L) = \frac{1}{2} - \frac{1}{3}\cos(\alpha + \beta)$$
$$P_{-\pm}^{QM}(L) = \frac{1}{2} + \frac{1}{3}\cos(\alpha + \beta) \tag{8}$$

Since in the impact series experiment we are considering detections at one side of the setup occur time-like separated after the detections at the other one, which measurement is made first and which after does not depend at all on any inertial frame. Therefore, in agreement with the principle that the effects cannot exist before the causes, it is reasonable to assume that the correlations appear because the photon impacting first chooses its outcome without being influenced by the parameters the photon impacting later will meet at the other arm of the setup, and the photon impacting later chooses its outcome taking account of the choice the photon impacting first has made.

The quantum mechanical predictions (Eq. (7),(8)) respect this causality view for Time ordering 1, but clearly violate it for Time ordering 2, and therefore one has to conclude that QM implies influences acting backward in time between time-like separated regions.

Could such a retrocausation effect be used to built a time machine? Consider the single probabilities for the subensemble with path difference l in Table (1). The superposition principle of QM states:

$$P_{\sigma\omega}^{QM}(l) = |A_{\sigma\omega}(l, ll) + A_{\sigma\omega}(L, Ll) + A_{\sigma\omega}(L, lL)|^2 \tag{9}$$

Substituting the amplitudes of (30), (31) and (32) in the Appendix into Eq. (9) one gets:

$$P_{+\pm}^{QM}(l) = \frac{1}{2} + \frac{1}{3}\cos(\alpha + \beta)$$

$$P_{-\pm}^{QM}(l) = \frac{1}{2} - \frac{1}{3}\cos(\alpha + \beta) \tag{10}$$

Eq. (8) and (10) together show that an observer watching only the detectors D_1 cannot become aware in the present of actions performed in the future of his light cone. However, according to QM the coincidences measurement should demonstrate such influences acting really backward in time. We are in a quite similar situation as for the faster than light influences involved in the Bell-experiments: in this case the coincidences measurement demonstrates real faster-than-light influences, even though these influences cannot be used for superluminal telegraphing.

3   Comments and Answers

COMMENT 1. *Paper [1] suffers from what I believe to be a severe problem. The author examines the probability of detection at a detector for one photon of a correlated pair, where the two photons traverse different interferometers. He then restrict attention to only those pairs which have a given path difference for the two photons. Unfortunately, there is absolutely no way of knowing what the path difference is which the two photons have traversed and still have the required interference. Ie, if the wave packets are sufficiently short that the timing of the arrival at the detectors can be used to determine that path difference, then the coherence of the photons in each of the paths is too short to allow the photons traversing different paths in the one detector to interfere. (L, LL) and (l, lL) will then not interfere with each other, and the expression (2) above for the quantum probability will not be correct. The correct one will be:*

$$|A_{\sigma\omega}(L, LL)|^2 + |A_{\sigma\omega}(l, Ll) + A_{\sigma\omega}(l, lL)|^2 \tag{11}$$

which is a very different expression. In general, quantum mechanics will always predict that the probabilities at detector 2 will be totally insensitive to the measurements, or the paths followed for particle 1, if those are unknown. There will be correlations between outcomes of the measurement made on particle 1, but the outcomes of measurements made on particle one will be independent of what kinds of measurements are made on particle 2. In this case the author has assumed that one can both determine the timing of the two particles with sufficient accuracy to differentiate between various possibilities, and at the same time have interference over time scales which are longer than that time scale.

This comment seems to overlook that the experiment involves two different coherence lengths, that of the pump laser light (of about 30 m), and that of the photon pair light (of about 10 μm).

Time-resolved detection [10, 11, 12] of the photon pairs cannot distinguish between the paths of subensemble L: (L, LL), (l, lL), (l, Ll), because all of them yield the same time difference in the detected photon pair signals. Neither can measurement of the time of emission of the pump laser light distinguish between these paths when, as assumed, the path difference $L - l$ (of about 0.3 m) between the long and the short path of each interferometer is much smaller than the pump beam coherence length. Therefore according to quantum mechanics the paths of subensemble L will interfere with each other, and for the same reasons the paths of subensemble l: (l, ll), (L, lL), (L, Ll), will also interfere with each other too.

On the contrary, time-resolved detection allows us to discriminate between the cases where a pair follows a path of subensemble L, and the cases where the pair follows a path of subensemble l. Therefore, if QM holds, a time delay spectrum of coincidence counts [10, 12] for each of the four possible outcomes $D_1(\sigma)$, $D_2(\omega)$, will exhibit four peaks: an interference peak corresponding to subensemble L we suppose set at time difference 0, a second interference peak at time difference $(l - L)/c$ corresponding to subensemble l, and two other peaks at time differences $(L - l)/c$ and $(2l - 2L)/c$ corresponding to path (l, LL), respectively (L, ll). Using a time difference window one can select only the events corresponding to subensemble L, or only those to subensemble l.

In conclusion, there is no problem of principle to perform the proposed experiment, and as regards the quantum mechanical predictions, expression (2) gives the correct quantum mechanical probability.

COMMENT 2. *Consider the case in which the detections at the right-hand side of the setup, in detectors D_2, lie time-like separated after the detections at the left-hand side, in detectors in D_1. By selecting the paths (L, LL), (l, Ll), (l, lL) through a time interval between the detection in one of the detectors D_1 and one of the detectors D_2 you are using information from side 2 to select events on side 1, and therefore determining the outcomes afterwards in time.*

I don't think that this explanation reproduces the quantum mechanical view. According to quantum mechanics one should considered that each particle travels all the three indistinguishable paths (L, LL), (l, Ll), (l, lL) at once. This means that:

1. The joint probabilities $P_{\sigma\omega}^{QM}$ predicted by the superposition principle result from contributions from these three paths alone, and

2. These three paths have to be considered absolutely equivalent to each other, i.e., each of them contributes the same amount to the quantity $P_{\sigma\omega}^{QM}$.

From these conditions it follows that even if the measurement selects only those counts in the detectors $D_i(\sigma)$ yielding path difference L through coincidence with the counts in the detectors $D_j(\omega)$, the measured distribution of the outcomes is the same as if it had been possible to perform the experiment nonselectively, with only the three paths belonging to

the subensemble L (what admittedly is not feasible).

But in the latter hypothetical case the causality principle requires single detection probabilities for the photon detected first depending only on the parameters it meets on its travel from S to the detector. As said, the quantum mechanical predictions (Eq. (7), (8)) clearly violate this requirement for Time ordering 2. Indeed the violation is plain since an observer watching only detectors D_1 would measure (in the hypothetical case) count rates (8) depending on choices of parameter β lying in his light-cone future, i.e., QM implies influences acting backward in time between time-like separated regions.

Notice that from a quantum mechanical point of view the selection of paths through detection time interval can very well be interpreted as a reversed preparation -a *retroparation*- [9], and the fact that we are not capable to perform the experiment using only the three paths referred to, is no argument against the existence of influences backwards in time, but only against the claim to use them for practical purposes, e.g. to build a Time Machine. The similarity with superluminal nonlocality is impressive, excepted obviously that Bell experiments have already been done and upheld QM, whereas the experiments we are discussing have not yet been done, and could in principle reject it.

COMMENT 3. *A very causal and superluminal interpretation holds for time ordering 2 (detections in D_2 time-like separated after detections in D_1): Detection of photon 1 determines the possible paths photon 2 can choose. If photon 1 is detected in $+$, then photon 2 is obliged to take a path such that the time interval between detections is L; conversely, if photon 1 is detected in $-$, then photon 2 is obliged to take a path such that the time interval between detections is l. I don't see any violation of causality (striking or not) in this fact.*

Indeed the dependence on $\cos(\alpha + \beta)$ exhibited by the single quantum mechanical probabilities $P_{+\pm}^{QM}$ at side 1 (left-hand side) of the setup (see Eq. (8)) clearly arise because in the interference at BS_{22} the paths (L, LL) and (l, lL), which carry out half of the terms of the second order interference at BS_{21}, do not interfere with the paths (L, Ll), (l, ll) which carry out the other half. This description assuming some kind of intermediate nonlocal correlations between the outcomes at side 1 and the output ports of BS_{21} is undoubtedly a superluminal causal, but not a quantum mechanical one. According to quantum mechanics it is detection what brings the wavefunction to collapse, and it is not ortodox to assume a kind of reduction before, i.e. you could if you wish assume the detection value on side 1 to determine the detection value on side 2, but it does not make sense (within the quantum mechanical view) to speak about "the path by which the photon leaves BS_{21}" if it gets detected only after BS_{22}.

Moreover it is clear that such an explanation with interferences in between cannot account for the functioning of the quantum mechanical superposition principle in the proposed experiment because of the terms coming from path (l, Ll). This path interferes at BS_{22} with the other two ones, but not at BS_{21}. The presence of this path produces terms in $\cos(\alpha + \gamma)$ which imply a direct nonlocal correlation between detections at side 1, in the detectors monitoring BS_{11}, and detections at side 2, in the detectors monitoring BS_{22}. Accordingly,

if detectors D_2 lie time-like separated after detectors in D_1, a dependence on $\cos(\alpha+\beta)$ of the single probabilities $P_{\pm\pm}^{QM}$ in detectors D_1 could only be interpreted as a retrocausal link.

COMMENT 4. **Assumed the superposition principle violates the causality principle in the proposed experiment, it seems clear that a nonlocal causal description must prescribe another rule to calculate the joint probabilities. In [1] it is proposed to assume there is no superluminal influence between side 1 and side 2. Why not to assume such influences at least between BS_{11} and BS_{21}?**

In a certain sense this has been done in [2], for in this paper a model was proposed assuming superluminal influences as well between BS_{11} and BS_{21} for half of the particles traveling (L, LL) and half of the particles traveling (l, lL), as between BS_{11} and BS_{22} for half of the particles traveling (L, LL) and half of the particles traveling (l, Ll). Meanwhile I think the most reasonable assumption is to exclude superluminal influences between BS_{11} and BS_{22} for all particles, and accept them between BS_{11} and BS_{21} for the particles traveling the paths (L, LL) and (l, lL).

Indeed nothing seems to speak against defining indistinguishability in a stronger way than quantum mechanics does, and state that a number of paths can produce interferences of a certain order at BS_{2l} only if all of them do interfere in any preceding interference of the same order at BS_{2k}, $k < l$. According to this assumption paths (L, LL), (l, Ll) and (l, lL) cannot be considered to interfere at BS_{22} because two of them (L, LL) and (l, lL) do interfere nonlocally at BS_{21}, but the third one (l, Ll) does not. We call this principle *causal indistinguishability* because the motivation to introduce it is to unify superluminal influences and causality principle within the frame of Relativistic Nonlocality or Multisimultaneity [3, 4]. In the next section we derive corresponding predictions.

We would like to point out that till the experiment proposed in Fig. 1 there has been no necessity to define indistinguishability in this more stronger way, for quantum mechanical indistinguishability reduces to *causal indistinguishability* in all setups considered before. This is also the case for the great variety of possible experiments with series of *before* and *non-before* impacts described in [6].

COMMENT 5. **Bell experiments with time-like separated impacts at the splitters have already been done [12] demonstrating the same correlations as for space-like separated ones. Cannot be said that such experiments, as well as Wheeler's "delayed-choice" ones, already demonstrate influences backward in time?**

Actually not. Regarding the experiment described in [12] Quantum Mechanics predicts single counts equally distributed for the photon impacting before. But this is also the prediction of the causal view according to which the photon impacting first chooses its outcome without being influenced by the parameters the photon impacting later will meet at the other arm of the setup. Therefore, concerning the experiment of [12] it is possible to account for the quantum mechanical predictions and the observed results by means of causal links acting forward in time.

Regarding Wheeler's "delayed-choice" experiments, they can be easily explained assuming unobservable subluminal causality acting forward in time, as for instance Bohm's causal model does, and the principles proposed in [6] also suggest.

4 Completing Multisimultaneity through the 'Causal Indistinguishability Condition'

We now extend the basic principles and theorems of RNL or Multisimultaneity presented in previous work [3, 4, 6, 7] to the impact series experiments proposed above, and show the necessity of defining indistinguishability in a stronger way. To this aim, we discuss impact series with moving beam-splitters involving Multisimultaneity (i.e. several simultaneity frames) and, as particular cases, the two possible time orderings in the experiment of Fig. 1 with beam-splitters at rest (i.e., involving only one simultaneity frame).

Remember that in Multisimultaneity the outcome values for detections after beam-splitter BS_{ik} are considered determined at the time of arrival at this beam-splitter, and not at the time of arrival at the detectors monitoring the output ports of BS_{ik}.

At time T_{ik} at which particle i ($i \in \{1, 2\}$) arrives at beam-splitter BS_{ik} we consider in the inertial frame of this beam-splitter which beam-splitters BS_{jl} particle j ($j \in \{1, 2\}, j \neq i$) did already reach, i.e. we consider whether the relation $(T_{ik} < T_{j1})_{ik}$ holds, or there is a BS_{jl} such that the relation $(T_{jl} \leq T_{ik} < T_{jl+1})_{ik}$ holds, the subscript ik after the parenthesis meaning that all times referred to are measured in the inertial frame of BS_{ik}.

Suppose first of all the case in which $(T_{11} < T_{21})_{11}$, and $(T_{2k} < T_{11})_{2k}$, for each k. This means the impacts of photon 1 on BS_{11} in the inertial frame of this beam-splitter to occur before the impacts of photon 2 on BS_{21}, and the impacts of photon 2 on each BS_{2k} in the inertial frame of BS_{2k} to occur before the impacts of photon 1 on BS_{11}. This obviously requires fast moving beam-splitters. All impacts are then called *before* ones, and labeled b_{ik}.

In this case the relativistic nonlocal causal view of Multisimultaneity states that the outcome choices at each beam-splitter take account of local information only (excepted obviously the information that the actual impact is a *before* one), i.e., the distribution of the outcome values of photon i in beam-splitter BS_{ik} are not influenced by the parameters the other photon j meets in side j of the setup.

Since we consider photon pairs that travel the paths (L, LL), (l, Ll), (l, lL), from the point of view of BS_{22} once photon 2 did impact, no ulterior detection makes it possible to distinguish between the path segments (lL) and (Ll). On the contrary one cannot yet exclude to know whether photon 2 traveled path segment (LL) by detecting particle 1 before it impacts on BS_{11}, since this impact did not yet happen in the inertial frame of BS_{22}. Therefore, from the point of view of BS_{22} path segments (lL) and (Ll) lead to first order interferences, and path segment (LL) does not interfere at all. As regards things considered from the point of view of BS_{11}'s inertial frame one cannot exclude that photon

2 is getting detected before it impacts on BS_{21} and reveals whether photon 1 did travel the long path (L) or the short one (l). Therefore no interference takes place at BS_{11}. Thus one is led to the relation:

$$P(b_{11}, b_{21}, b_{22})_{\sigma\omega} = |A_\sigma(L)|^2 |A_\omega(LL)|^2 + |A_\sigma(l)|^2 |A_\omega(Ll) + A_\omega(lL)|^2, \qquad (12)$$

where $P(b_{11}, b_{21}, b_{22})_{\sigma\omega}$ denotes the joint probability of getting photon 1 detected in $D_1(\sigma)$ and photon 2 in $D_2(\omega)$ for the paths of subensemble L when all impacts at both sides are *before* ones, and $A_\sigma(path)$, $A_\omega(path)$ are the first order amplitudes for the indicate path segments.

Substituting into (12) according to (33), (34), and (35) in the Appendix one gets the following joint probabilities:

$$P(b_{11}, b_{21}, b_{22})_{\sigma\omega} = \frac{1}{4} + \omega \frac{1}{6} \cos(\beta - \gamma) \qquad (13)$$

Eq. (13) yields the following single probabilities for side 2:

$$P(b_{22})_\omega = \frac{1}{2} + \omega \frac{1}{3} \cos(\beta - \gamma) \qquad (14)$$

and for side 1:

$$P(b_{11})_\sigma = \frac{1}{2} \qquad (15)$$

i.e. as regard the outcome distribution for the single detectors $D_2(\omega)$ when the impacts on BS_{22} are *before* ones Multisimultaneity agrees with the time ordering insensitive predictions of Quantum Mechanics in (7). On the contrary, as regard the outcome distribution for the single detectors $D_1(\sigma)$ when the impacts on BS_{11} are *before* ones Multisimultaneity clearly conflicts with what Quantum Mechanics predicts in (8), i.e.:

$$P(b_{11})_\sigma \neq P_{\sigma\pm}^{QM} \qquad (16)$$

Consider now the situation in which $(T_{11} < T_{21})_{11}$, and $(T_{2k} \geq T_{11})_{2k}$, for each k. This situation is given in the arrangement of Fig.1 with beam-splitters at rest and set in place according to time ordering 2. In such experiments, can the impacts on BS_{21} and BS_{22} be considered together to be *non-before* ones?

They cannot, because detections after BS_{11} and BS_{21}, and detections after BS_{11} and BS_{22} do not share the same subensemble of indistinguishable paths, or, in other words, from the three paths (L, LL), (l, lL), (l, Ll) interfering with each other at BS_{11} and BS_{22}, only two (L, LL), (l, lL) interfere with each other at BS_{11} and BS_{21}.

In fact the assumption that these impacts are a_{21}, a_{22}, i.e. *non-before* ones, bears oddities, since then according to the principles of Multisimultaneity the sum-of-amplitudes rule would apply, and therefore on the one hand it holds that:

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$$P(b_{11}, a_{21}, a_{22})_{\sigma\omega} = P_{\sigma\omega}^{QM}, \tag{17}$$

and on the other hand it holds that:

$$P(b_{11}, a_{21}, a_{22})_{\sigma\omega} = P(b_{11})_{\sigma} P\Big((a_{21}, a_{22})_{\omega} | (b_{11})_{\sigma}\Big). \tag{18}$$

From Eq. (17) and (18) it follows that:

$$P_{\sigma\pm}^{QM} = P(b_{11}, a_{21}, a_{22})_{\sigma\pm}$$
$$= P(b_{11})_{\sigma} \Big[P\Big((a_{21}, a_{22})_{+}(L) | (b_{22})_{\sigma}\Big) + P\Big((a_{21}, a_{22})_{-} | (b_{22})_{\sigma}\Big) \Big]$$
$$= P(b_{11})_{\sigma} \tag{19}$$

which contradicts Eq. (16).

This contradiction just means that in this experiment the sum-of-amplitudes rule violates the causal view of Multisimultaneity and, therefore the probabilities have to be calculate otherwise.

If the impact on BS_{21} and the subsequent impact on BS_{22} cannot be both together *non-before* ones, then a quite reasonable assumption can be to treat the first of them as *non-before* impact for the paths (L, LL), (l, lL) interfering with each other at BS_{11} and BS_{21}, and the impact on BS_{22} as *before* one yielding only first degree interferences for the paths (l, lL) and (l, Ll). More in general we introduce the following interference condition:

Causal Indistinguishability Condition: A number of paths can produce interferences of a certain order at BS_{il} only if all of them do interfere in any preceding interference of the same order at BS_{ik}, $k < l$.

Taking account of this condition within Multisimultaneity one is lead to the following rules:

1. Path (L, LL) and path (l, lL) produce nonlocal 2-photon interferences at BS_{11} and BS_{21}.

2. Path (l, Ll) and path (l, lL) produce single photon interferences at BS_{22}.

3. Path (L, LL) and path (l, Ll) do not produce nonlocal 2-photon interferences at BS_{11} and BS_{22}.

Moreover as stated in [6] we assume all paths involved in an interference to contribute the same way to the outcome distribution, i.e. each path yields the same probability for a determined outcome. According to these rules, the single paths give the following contributions to the joint probabilities:

$$P(b_{11}, a_{21}, b_{22})_{\sigma\omega}(L, LL) = \frac{1}{4}\Big[1 - \sigma\omega\cos(\alpha + \beta)\Big]$$

$$P(b_{11}, a_{21}, b_{22})_{\sigma\omega}(l, lL) = \frac{1}{4}\Big[1 - \sigma\omega\cos(\alpha + \beta)\Big]\Big[1 + \sigma\omega\cos(\gamma - \beta)\Big]$$

$$P(b_{11}, a_{21}, b_{22})_{\sigma\omega}(l, Ll) = \frac{1}{4}\Big[1 + \sigma\omega\cos(\gamma - \beta)\Big] \tag{20}$$

Equations (20) yield the total joint probabilities:

$$P(b_{11}, a_{21}, b_{22})_{++} = \frac{1}{12}\Big[3 - 2\cos(\alpha + \beta) + 2\cos(\gamma - \beta) - \cos(\alpha + \beta)\cos(\gamma - \beta)\Big]$$

$$P(b_{11}, a_{21}, b_{22})_{+-} = \frac{1}{12}\Big[3 - 2\cos(\alpha + \beta) - 2\cos(\gamma - \beta) + \cos(\alpha + \beta)\cos(\gamma - \beta)\Big]$$

$$P(b_{11}, a_{21}, b_{22})_{-+} = \frac{1}{12}\Big[3 + 2\cos(\alpha + \beta) + 2\cos(\gamma - \beta) + \cos(\alpha + \beta)\cos(\gamma - \beta)\Big]$$

$$P(b_{11}, a_{21}, b_{22})_{--} = \frac{1}{12}\Big[3 + 2\cos(\alpha + \beta) - 2\cos(\gamma - \beta) - \cos(\alpha + \beta)\cos(\gamma - \beta)\Big] \tag{21}$$

From (21) one gets the multisimultaneous causal correlation coefficient:

$$E = \sum_{\sigma,\omega}(-\sigma\omega)P(b_{11}, a_{21}, b_{22})_{\sigma\omega} = \frac{1}{3}\cos(\alpha + \beta)\cos(\gamma - \beta), \tag{22}$$

the single probabilities for the left-hand side:

$$P(b_{11})_{\sigma} = \frac{1}{2} - \sigma\frac{1}{3}\cos(\alpha + \beta), \tag{23}$$

and the single probabilities for the right-hand side:

$$P(b_{22})_{\omega} = \frac{1}{2} + \omega\frac{1}{3}\cos(\beta - \gamma). \tag{24}$$

As regards other possible time orderings with beam-splitters at rest, it is easy to see that for all of them the *Causal Indistinguishability Condition* forbids second order interferences at BS_{22}, and therefore the preceding Eq. (22), (23), and (24) hold. Hence, contrarily to the experiment proposed in [6], the experiment of Fig. 1 with all beam-splitters resting in the laboratory frame does not make possible to arrange a *non-before* impact at each side of the setup and, therefore, is insensitive for different time orderings.

As regards the time ordering in which the impacts on BS_{11} and BS_{21} become both *before* ones by means of fast moving beam-splitters, no second order interference takes place at these beam-splitters. Accordingly the *Causal Indistinguishability Condition* does not forbid the impact on BS_{22} to be a *non-before* one. This (b_{11}, b_{21}, a_{22}) case is discussed in a separated article, and shown that rules different from conventional superposition and

sum-of-probabilities may apply, as it is the case for the corresponding (b_{11}, b_{21}, a_{22}) experiment discussed in [6].

In summary, Eq. (7), (8), and (23), (24), show that regarding single detections at both sides the multisimultaneous model with Causal Indistinguishability Condition yields the same single detection values than Quantum Mechanics. On the contrary (4) and (22) show the two theories to conflict regarding the correlation coefficient for joint probabilities.

Notice that RNL or Multisimultaneity, though causal, is a specific superluminal nonlocal theory. That it conflicts with QM suggests that the issues of superluminal nonlocality and of retrocausation are not really entangled, and should be conceptually distinguished: Nothing speaks in principle against the possibility that Nature uses faster-than-light influences but avoids backward-in-time ones.

5 Real experiment

A real experiment can be carried out arranging the setup used in [12] in order that the photon traveling the long fiber of 4.3 km impacts on a second beam-splitter before it is getting detected. For phase values fulfilling the relations:

$$
\begin{aligned}
\alpha + \gamma &= 0, \\
\alpha + \beta &= \frac{\pi}{2}, \\
\beta - \gamma &= \frac{\pi}{2},
\end{aligned}
\tag{25}
$$

the equations (4) and (22) yield the predictions:

$$
\begin{aligned}
E^{QM} &= \frac{2}{3} \\
E &= 0
\end{aligned}
\tag{26}
$$

Hence, for settings according to (25), e.g., $\alpha = 45°$, $\beta = 45°$, $\gamma = -45°$, the experiment represented in Fig. 1 allow us again to decide between quantum mechanics and the multisimultaneous causal model proposed above, through determining the corresponding experimental quantities from the four measured coincidence counts $R_{\sigma\omega}$ in the detectors.

6 Conclusion

The quantum mechanical predictions for the experiment represented in Fig.1 with detections at side 2 lying time-like separated after detections at side 1, cannot be reproduced through links forwards in time, neither through such between the detectors, nor through intermediate links between the beam-splitters BS_{11} and BS_{21}. Therefore upholding of

quantum mechanics by experiment would mean that we would have to learn living with influences backward in time as we have learnt living with influences faster than light.

The alternative case of experiment contradicting Quantum Mechanics does not mean to give up influences faster than light, but only influences backward in time arising from the way QM manages indistinguishability and superposition. Superluminal nonlocality and retrocausation are not necessarily entangled: in the frame of Multisimultaneity, both superluminal causal links and the impossibility of influences acting backwards in time have the status of principles.

We would like to finish by stressing that the "overwhelming experimental success" of quantum mechanics cannot be advanced as a valid reason against doing the proposed impact series experiments. Effectively in all experiments already done both concepts, conventional quantum mechanical indistinguishability and the new *Causal Indistinguishability Condition* proposed above, are indistinguishable from each other so that the "overwhelming experimental success" is so far shared by both. Moreover causal indistinguishability looks to be a more sharply defined concept than the quantum mechanical one. Therefore, in order to distinguish the way nature does really work, it is necessary to perform experiments in which both indistinguishabilities become distinguishable. Whatever the answer may be, impact series experiments seem capable of bearing a promising controversy between QM and Causality, similar to the controversy between QM and Local Realism.

Acknowledgements

Appendix

In the following are listed the probability amplitudes of the path pairs and the single paths we are interested in.

A.1 Probability Amplitudes of the path pairs with length difference L in Table (1)

We denote $A_{\sigma\omega}(\text{path})$ the probability amplitude associated to detection of photon 1 in $D_1(\sigma)$ and of photon 2 in $D_2(\omega)$, for the specified path. The probability amplitudes for the path pairs of subensemble L in (1) normalized to only these three path pairs are:

$$(l, Ll) \quad : \quad \begin{cases} A_{++}(l, Ll) & = & -A_{--}(l, Ll) & = & -\frac{1}{\sqrt{3}}\frac{1}{2}e^{i\beta} \\ A_{+-}(l, Ll) & = & A_{-+}(l, Ll) & = & -i\frac{1}{\sqrt{3}}\frac{1}{2}e^{i\beta} \end{cases} \quad (27)$$

$$(l, lL) \quad : \quad \begin{cases} A_{++}(l, lL) &=& A_{--}(l, lL) &=& -\frac{1}{\sqrt{3}} \frac{1}{2} e^{i\gamma} \\ A_{+-}(l, lL) &=& -A_{-+}(l, lL) &=& i\frac{1}{\sqrt{3}} \frac{1}{2} e^{i\gamma} \end{cases} \tag{28}$$

$$(L, LL) \quad : \quad \begin{cases} A_{++}(L, LL) &=& -A_{--}(L, LL) &=& \frac{1}{\sqrt{3}} \frac{1}{2} e^{i(\alpha+\beta+\gamma)} \\ A_{+-}(L, LL) &=& A_{-+}(L, LL) &=& -i\frac{1}{\sqrt{3}} \frac{1}{2} e^{i(\alpha+\beta+\gamma)} \end{cases} \tag{29}$$

A.2 Probability Amplitudes of the path pairs with length difference l in Table (1)

The probability amplitudes for the path pairs of subensemble l in (1) normalized to only these three path pairs are:

$$(l, ll) \quad : \quad \begin{cases} A_{++}(l, ll) &=& -A_{--}(l, ll) &=& \frac{1}{\sqrt{3}} \frac{1}{2} \\ A_{+-}(l, ll) &=& A_{-+}(l, ll) &=& \frac{1}{\sqrt{3}} \frac{1}{2} i \end{cases} \tag{30}$$

$$(L, lL) \quad : \quad \begin{cases} A_{++}(L, lL) &=& -A_{--}(L, lL) &=& \frac{1}{\sqrt{3}} \frac{1}{2} e^{i(\alpha+\gamma)} \\ A_{+-}(L, lL) &=& A_{-+}(L, lL) &=& -\frac{1}{\sqrt{3}} \frac{1}{2} i\, e^{i(\alpha+\gamma)} \end{cases} \tag{31}$$

$$(L, Ll) \quad : \quad \begin{cases} A_{++}(L, Ll) &=& A_{--}(L, Ll) &=& \frac{1}{\sqrt{3}} \frac{1}{2} e^{i(\alpha+\beta)} \\ A_{+-}(L, Ll) &=& -A_{-+}(L, Ll) &=& \frac{1}{\sqrt{3}} \frac{1}{2} i\, e^{i(\alpha+\beta)} \end{cases} \tag{32}$$

A.3 Probability Amplitudes of the single path segments LL, Ll, lL traveled by photon 2

We denote $A_\sigma(\text{path})$ the probability amplitude associated to detection of photon 2 in $\mathrm{D}_2(\sigma)$, for the specified path segment. The probability amplitudes for the path segments LL, Ll, lL photon 2 travels in an experiment selecting the path pairs with path difference L in (1), normalized as if the experiment were performed with only these three paths are:

$$(Ll) \quad : \quad \begin{cases} A_+(Ll) &=& -\frac{1}{\sqrt{3}} \frac{1}{\sqrt{2}} e^{i\beta} \\ A_-(Ll) &=& -i\frac{1}{\sqrt{3}} \frac{1}{\sqrt{2}} e^{i\beta} \end{cases} \tag{33}$$

$$(lL) \quad : \quad \begin{cases} A_+(lL) &=& -\frac{1}{\sqrt{3}} \frac{1}{\sqrt{2}} e^{i\gamma} \\ A_-(lL) &=& i\frac{1}{\sqrt{3}} \frac{1}{\sqrt{2}} e^{i\gamma} \end{cases} \tag{34}$$

$$(LL) \quad : \quad \begin{cases} A_+(LL) &=& -\frac{1}{\sqrt{3}} \frac{1}{\sqrt{2}} e^{i(\beta+\gamma)} \\ A_-(LL) &=& i\frac{1}{\sqrt{3}} \frac{1}{\sqrt{2}} e^{i(\beta+\gamma)} \end{cases} \tag{35}$$

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